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THESIS

MEASURING CAPABILITY
OF
SURFACE COMBATANTS

by

William P. Hoker

March 1985

Thesis Advisor: R. E. Looney

Approved for public release; distribution unlimited

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Measuring overall warfare capability of surface combatants is the purpose of this thesis. Surface combatants chosen were those displacing more than 1000 tons, in the Japanese Maritime Self Defense Force and the Soviet Pacific Fleet. The method used here involves measuring some ship and system capabilities directly by the constant sum method, and finding a functional relationship between ship capability and ship characteristics, by multiple regression.

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Measuring Capability of Surface Combatants

by

William P. Hoker
Lieutenant, United States Navy
B.S., United States Naval Academy, 1979

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Measuring overall warfare capability of surface combatants is the purpose of this thesis. Surface combatants chosen were those displacing more than 1000 tons, in the Japanese Maritime Self Defense Force and the Soviet Pacific Fleet. The method used here involves measuring some ship and system capabilities directly by the constant sum method, and finding a functional relationship between ship capability and ship characteristics, by multiple regression.

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I. INTRODUCTION

An important problem in military operations research is weapon system 'capability' measurement, or 'effectiveness' measurement. We desire a concise index of capability for comparative purposes and to answer such questions as:

--How much more capable is system A than system B?

--If certain characteristics were changed in system A, how would its overall capability then change?

A common approach involves describing a system in an engineering sense. Various relationships are identified and calculated, such as turn radius, thrust to weight ratio, etc. Unfortunately one is then left with several measures to compare. Which is the most important? What are the interactions between characteristics? This approach, while objective, cannot capture the relationship between characteristics, and does not provide a succint measure of capability. It cannot answer questions about how much more capable one system or another is.

We need to think about the problem in a different manner. Since systems are composed of characteristics, it might be helpful to consider system capability as some function of those characteristics. What we seek then, is a functional relationship of the form:

$$Yi = f(Xi1, Xi2, \ldots, Xim) \quad i=1,2,\ldots,n \quad m \leq n$$

where

Yi = capability of system i

Xij = jth characteristic of system i.

The relationship can then be applied to any similar system whose characteristics are known, to arrive at an overall capability measure.

A method will be presented here to find and apply that relationship. The method requires that, once the system type is selected, 'sample' systems along with their characteristics be presented to experts to judge on the basis of overall capability. Multiple regression procedures are then used to find an equation linking the judged capabilities to the characteristics.

One advantage to the regression approach is that it accurately reflects the way judges valued the characteristics relative to overall capability and to each other. Another advantage is that it is testable. Once the equation is derived, it can be tested to ensure conformance with the judges' responses. Still another advantage is that regression procedures are available in most computer statistics packages.

Chapter II will outline selection of the system type and characteristics, selection of the judges, introduce the constant sum scaling method, and address preparation of the questionaire. Chapter III will address the constant sum scaling method more thoroughly, and illustrate it using our actual data. Then Chapter IV will concentrate on finding the functional relationship between system capability and characteristics. Application of the model and discussion of results is the focus of Chapter V. Finally, Chapter VI will summarize and present major conclusions.

II. RESEARCH DESIGN

A. SELECTION OF SYSTEM TYPE

Surface combatants represent a significant challenge for capability measurement since they are large weapon systems composed of numerous subsystems, many of which are designed for different purposes. Surface combatants displacing more than 1000 tons from the Soviet Pacific fleet and Japanese Maritime Self Defense Force were chosen for this study [Ref. 1].

Both fleets are approximately the same size, and the platforms have well-known characteristics. A scenario involving the two fleets will also be easy to develop for judging purposes.

B. CHARACTERISTICS

To determine characteristics, we consider the ships in a scenario for which they likely may have been designed: surface, subsurface conventional warfare in the Sea of Japan and Sea of Okhotsk between Soviet and Japanese Naval forces. Anti-Submarine warfare (ASW) is expected to be a high priority consideration as is Anti-Air warfare (AAW).

Ten characteristics were considered most important in determining warfare capability. They are listed here in the exact versions in which they appear in the two fleets.

1. Year Launched. This is the year the ship was launched. Hopefully it will serve as a technology level indicator. Versions: before 1965; 1965-1975; 1975-1985.
2. Displacement. Chosen for a measure of survivability. Versions: less than 3500 tons; 3500-5000 tons; over 5000 tons.

3. Anti-Submarine Warfare (ASW) Missile. Numbers refer to quantity of missiles. Versions: 8 SS-N-14; 4 SS-N-14; 8 ASROC.

4. Miscellaneous ASW Weapons. Versions: torpedoes; torpedoes & ASW rockets (such as RBU 6000 or Hedgehog); torpedoes, ASW rockets, & depth charges.

5. Sonar. Versions: hull mounted; hull mounted & variable depth sonar (VDS); hull mounted, VDS, & towed array.

6. ASW Helicopter. Versions: 3 SH-3; 1 SH-3; 1 Hormone A.

7. Surface to Air Missile (SAM). Here numbers of each version refer to launchers. Versions: 2 SA-N-3 & 2 SA-N-4; 1 Sea Sparrow; 2 SA-N-3; 2 SA-N-1; 1 SA-N-1; 1 SA-N-4; 2 SA-N-4; 1 SM-1MR.

8. Surface to Surface Missile (SSM). Again, numbers of missiles refer to the amount of missiles. Versions: 8 SS-N-3B; 4 SS-N-2C; 8 Harpoon; 4 SS-N-3B.

9. Close In Weapon System (CIWS). These are guns only. Numbers refer to gun mounts. Versions: 4 ADMG 630; 2 Vulcan Phalanx.

10. General Purpose Anti-Aircraft (AA) Gunfire Rate. These are guns of less than 77mm. Their rate of fire is the only real distinguishing feature, as their bore sizes and ranges are so similar that they can be excluded. Versions: 20 or less rounds/minute (rpm); 21-75 rpm; over 75 rpm.

Due to a desire to keep this report unclassified, electronic intelligence gathering or countering equipment cannot be considered.

C. SAMPLES

Now that we have decided upon a general group of ships and characteristics, we need to pick some specific platforms

with which to illustrate our method. Naturally not all platforms possess all characteristics; it is important therefore to ensure we have a good mix of ships with all characteristics represented. A dozen would seem to be the minimum necessary for judging and subsequent regression. This is based on scaling considerations as well as mathematical requirements. The constant sum scaling method requires, for n items to be scaled, $n(n-1)/2$ comparisons to be made; so we would like n to be a small as possible. On the other hand, if there are ten characteristics, we need at least 11 ships for any kind of meaningful multiple regression. These subjects will be treated in greater detail later.

These then are the specific ship types to be judged, and upon which our functional relationship will be developed: KARA, KRESTA II, KRIVAK I, KYNDA, KASHIN, HARUNA, DINA (our name for the Japanese '81 class DDG), TAKATSUKI, TACHIKAZE, HATSUYUKI, YAMAGUMO, and AMATSUKAZI. Table VI in Appendix A displays sample ships and their characteristics.

D. JUDGE SELECTION

Thirty United States Naval Officers specializing in Surface Warfare were selected as judges.

E. SCALING METHOD AND QUESTIONAIRE

The constant sum scaling method yields ratio scale data, which is required if one is to answer questions regarding how much better (or worse) one system or another is.

A judge is presented with the n items, or instances, to be ranked or scaled. Each instance is compared with each other instance, by pairs. As mentioned, if there are n instances, there are $n(n-1)/2$ pairs or comparisons. The judge is to split 100 points between the pair, assigning a

higher score to the instance possessing more of a specified trait. In our case of course the trait will be warfare capability. An example of the survey used in this study is shown in Appendix A. The survey is divided into several sections, each section corresponding to a group of characteristics, or the ships. Within each section of the characteristics, every combination or version in which they appear on the sample ships is presented for scaling. For example, for CIWS only two versions appear on the ships: either 4 ADMG 630s or 2 Vulcan Phalanxes. Therefore a judge need make only one comparison. However for SAMs there are 8 different versions or combinations which appear on the ships so $(8x7)/2 = 23$ comparisons must be made. After characteristics are scaled each version will have an index of capability. Then judges must scale the 12 ships against each other, giving each ship an index of capability.

In the next chapter the constant sum method will be addressed in detail and illustrated with our actual data.

III. ILLUSTRATION OF THE CONSTANT SUM METHOD OF SCALING

A. THEORY AND PROCEDURES

As mentioned, the constant sum method produces ratio scaled data, and is designed either to have a natural origin or one on which judges will agree [Ref. 2]. We will describe the method in detail and illustrate it using the SAM data in Appendix B.

1. The aij Matrix

Notationally, let aij be the amount of points assigned to instance j when compared to instance i. Say there are m judges; there would then be m of each aij or m aij matrices whose cross diagonal elements sum to 100 (aij + aji) and whose diagonal elements equal 50 (aij compared to itself). In our case, we have 30 judges so m=30.

2. The A Matrix

A new matrix A is constructed by taking the arithmetic mean of all these aij matrices; its individual elements are then the arithmetic means of the individual aij's:

$$Aij = \frac{\sum_{(i)}^{m} aij}{m}$$

3. The W Matrix

Now the matrix W is constructed whose elements are the cross diagonal ratios of the A elements, or,

$$Wij = \frac{Aij}{Aji}$$

Note that cross diagonal elements in W are reciprocals, and diagonal elements are 1. Now let S be the scale value (or capability value) that we desire. Each element Wij is an estimate of the ratio of Si and Sj, or,

$$Wij \approx \frac{Sj}{Si}$$

because each element Wij is the ratio:

(the average number of points awarded to j compared to i)

(the average number of points awarded to i compared to j).

In general there are more of these estimates Wij than there are instances to be scaled so the solution to the matrix W is overdetermined.

4. Scale Values

To resolve the problem of having multiple estimators for each scale value, a least squares approach is used. If

$$Wij = \frac{Sj}{Si}$$

then the estimation would be perfect. Taking the log of both sides yields:

$$\ln Wij - (\ln Sj - \ln Si) = 0$$

and the best solution is obtained by finding values of Sj and Si that keep ln Wij - (ln Sj - ln Si) as close to zero as possible, for all pairs of i and j. Therefore values are sought for S1,S2,S3,...,Sn that minimize

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{n} [\ln Wij - (\ln Sj - \ln Si)]^2$$

or

$$\min Q = \sum_{i=1}^{n} \sum_{j=1}^{n} [(\ln Wij)^2 - 2\ln Wij \ln Sj + 2\ln Wij \ln Si + (\ln Sj)^2 - 2\ln Si \ln Sj + (\ln Si)^2].$$

This is done by taking the n partial derivatives of Q with respect to Sj, and setting them equal to zero:

$$\frac{\partial Q}{\partial Sj} = 0, \quad j=1,2,\ldots,n.$$

$$\frac{\partial Q}{\partial Sj} = \sum_{i=1}^{n} \sum_{j=1}^{n} \left[\frac{-2\ln wij}{Sj} + \frac{2\ln Sj}{Sj} - \frac{2\ln Si}{Sj}\right] = 0$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} [-\ln Wij + \ln Sj - \ln Si] = 0$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} \ln Sj = \sum_{i=1}^{n} \sum_{j=1}^{n} [\ln Wij + \ln Si]$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} \ln Sj = \sum_{i=1}^{n} \sum_{j=1}^{n} \ln Wij + \sum_{i=1}^{n} \sum_{j=1}^{n} \ln Si$$

or

$$\ln Sj = \frac{\sum_{i=1}^{n} \ln wij}{n} + \frac{\sum_{i=1}^{n} \ln Si}{n} \; ; \; j=1,2,\ldots,n.$$

For our ratio scale, the unit is arbitrary. It would thus be convenient to set the average of the logs of the scale values equal to zero:

$$\frac{\sum_{i=1}^{n} \ln Si}{n} = 0$$

This makes a simple expression for the least squares estimates of the scale values:

$$\ln Sj = \frac{\sum_{i=1}^{n} \ln Wij}{n} \quad ; \quad j=1,2,\ldots,n.$$

or

$$Sj = \left[\prod_{i=1}^{n} Wij \right]^{1/n} \quad ; \quad j=1,2,\ldots,n.$$

These scale values are the geometric means of the W matrix jth column.

B. RESULTS

W matrices, A matrices, and scale values for all characteristics other than Surface to Air Missiles are shown in Appendix C. Scale values only for all characteristics and ships are displayed in Appendix D.

IV. FINDING THE FUNCTIONAL RELATIONSHIP

At this point we have measures or indices of capability for each version of all characteristics, and all ships (Appendix D). The link connecting judged ship capability scale values with characteristics scale values will now be explored. By viewing ship capability as a dependent variable, and characteristics scale values as independent variables, multiple regression can be used to relate the two. Subsequent regression analysis was performed using the APL function REGRESS from the OA3660 Workspace, Naval Postgraduate School. This function supplies an ANOVA table; coefficient of determination (R^2); standard error (SE); a list of coefficients for the regression equation; t-statistics for the coefficients; predicted values for the independent variables using the regression model; a matrix of variance-covariance; residuals; and a plot of the residuals. All APL functions used in the analysis can be found in Appendix E. A rough outline of multiple regression, and statistical procedures related to it will be addressed below in order to highlight some of the more salient features.

Multiple regression will yield a relationship, linear or non-linear, between the independent and dependent variable, of the form

$$Yi = a + \sum_{j=1}^{n} bjXij + ei \quad i=1,2,\ldots,n$$

where

Yi, the dependent variables, are the ship capabilities;
Xij, the independent variables, are the characteristics scale values, and can be linear or non-linear.
a is a constant term;
bj is a coefficient; and

ei is a term accounting for error in the estimating equation.

In order to solve a system of simultaneous equations

$Yi = f(Xi1, Xi2, \ldots, Xim)$ $i=1,2,\ldots,n$ $j=1,2,\ldots,m$

a mathematical requirement is that $n \geq m$. Otherwise, some j's will be in terms of other j's, and a unique solution cannot be found. That is one reason for picking 12 ships to regress on the 10 characteristics. A statistical reason is the desire for a large number of degrees of freedom. Because degrees of freedom are indicators of the numbers of sources of variability, in general the greater the df, the stronger will be our relationship. With 12 ships and 10 characteristics, there are nominally 2 df; one might surmise however that not all characteristics would be statistically significant, thus effectively increasing the df when regression was performed on the significant characteristics. This is indeed the case here as will be shown.

The regression equation provides a prediction or explanation of the relationship between the independent and dependent variables, and the output from the regression package purports to show how much in error the equation is, or how close the equation fits.

A. EQUATION CRITERIA

1. R^2

The R^2 is a rough measure of how well the equation accounts for variations in the dependent variables. Since it is basically the ratio between the explained part of the regression equation to the explained unexplained part, the higher the R^2, the better.

$$R^2 = \frac{\text{Regression sum of squares}}{\text{Regression sum of squares + Residual sum of squares}}$$

2. Standard Error (SE)

This is an estimate for the standard deviation of the actual Y from the predicted Y. Hence, the smaller the SE, the better.

$$SE = \left[\sum_{i=1}^{n} (Yi - \hat{Yi})^2\right]^{1/2}$$

where:

Yi = Judged capability.

$\hat{Yi}$ = Model predicted capability.

3. F-Ratio (F)

This statistic is basically a ratio of the explained part of the equation to the unexplained part; bigger is better.

$$F = \frac{\text{Regression mean squares}}{\text{Residual mean squares}}$$

4. Residual Mean Square Error (MSE)

This is an average of the unexplained deviation, so lower is better. Although it is incorporated in the F-ratio, it is important to look at it on its own, to examine it for absolute magnitude. A ratio can hide some very large numbers.

5. t-Statistics (t)

These are provided for the constant term a, and the regression coefficients, bj. They are some indications of the statistical significance of the particular term, a or bj. A complete explanation of the t-statistic is somewhat lengthy; however the t roughly implies whether or not a coefficient a or bj may = 0, in the regression model

$$Yi = a + \sum_{j=1}^{n} bjXij + ei \quad i=1,2,\ldots,n$$

If $|ti| < t_{1-\alpha}(n-k)$

where

$t_{1-\alpha}(n-k)$ = value from t-table with significance level α and n-k degrees of freedom

then that coefficient might equal 0 and therefore not be significant in the model, or, not contribute significantly to the relation. Thus, the higher the t, the better.

6. Residuals

A plot of the residuals--the differences between predicted Y's and the actual Y's--should be patternless. In other words, there should be an approximately equal number of positive and negative residuals, and there should not be an easily discernable pattern among the residuals, like a steady increase, etc. Additionally we might examine the residuals for the maximums: if the maximum is too large, the regression equation could be considered unacceptable. So although regression uses least squares criterion it may be useful to apply a sort of Chebyshev criterion as well.

7. Coefficients

Because we are looking for an equation linking ship capability to characteristics, the equation must make sense.

In this regard, all coefficients that multiply characteristics must be greater than 0. None of these characteristics can reasonably be expected to detract from performance, so multiplication by a negative number is unacceptable. Also, the coefficients may just look wrong. It is important to not just blindly apply statistical techniques but to look carefully at the results. A potential equation may have statistics indicating a good fit but we must also look to see if the equation changes the judges capability values significantly in terms of rank order. The goal is an equation or relation that accurately captures the judgement of the experts.

Table 1 summarizes equation criteria.

TABLE I

Equation Criteria

Bigger is Better:	Smaller is Better:
R^2, F, t	SE, MSE

Residuals: patternless, acceptable maximum

Coefficients: > 0

B. PROCEDURES

1. Arranging the Data

Thus far we have determined what we are looking for in a functional relationship; now we must decide how to get the relationship. We begin by arranging the data in a useful manner, by setting out the independent variable Yi's,

and the dependent variable Xij's. Table II is similar to Appendix D except that ships and characteristics have been replaced by their scale values, and arranged in a matrix format. If a ship does not possess a certain characteristic, it is replaced by a 0, meaning no capability. For example Y4, the Kresta II, is 1.69 which is the scale value of its capability from Appendix D. X41, the Kresta II's Year Launched, is 1.104, which is the scale value for '1965-1975' from Appendix D. It has 8 SS-N-14 ASW Missiles so X43 = 1.805, and since it has no surface to surface missiles, X46 = 0. The characteristics are arranged in a 12x10 matrix, called XX, and the ships are arranged into a vector of length 12 called YY.

TABLE II

Regression Variables

Independent Variables

Y1: KARA	Y2: KRIVAK I	Y3: KASHIN
Y4: KRESTA II	Y5: KYNDA	Y6: HARUNA
Y7: DINA	Y8: TAKATSUKI	Y9: TACHIKAZE
Y10: HATSUYUKI	Y11: YAMAGUMO	Y12: AMATSUKAZI

Dependent Variables

Xi1: Year Launched	Xi2: Displacement
Xi3: ASW Missile	Xi4: Miscellaneous ASW Weapons
Xi5: Sonar Type	Xi6: ASW Helicopter
Xi7: SAM	Xi8: SSM
Xi9: CIWS	Xi10: AA Gunfire Rate

Yi

Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12
4.34	0.969	0.546	1.69	1.38	1.23	2.79	0.723	0.687	1.54	0.478	0.732

Xij

Xi1	Xi2	Xi3	Xi4	Xi5	Xi6	Xi7	Xi8	Xi9	Xi10
1.104	1.272	1.805	0.9763	1.03	0.5439	3.514	0	0.9354	1.111
1.104	0.734	0.6284	0.9763	1.03	0	0.3108	0	0	1.111
1.104	1.071	0	0.9763	0.3087	0	1.202	0	0	1.111
1.104	1.272	1.805	0.9763	0.3087	0.5439	1.594	0	0.9354	1.505
0.4189	1.071	0	0.9763	0.3087	0	0.5998	1.905	0.9354	1.111
1.104	1.071	0.8817	0.5353	0.3087	3.142	0	0	0	1.111
2.162	1.071	0	0.5353	0.3087	0.5851	1.599	1.478	1.069	1.111
1.104	0.734	0.8817	0.9763	1.03	0	0	0	0	1.111
2.162	1.071	0.8817	0.5353	0.3087	0	1.599	0	0	1.111
2.162	0.734	0.8817	0.5353	0.3087	0.5851	0.7679	1.478	1.069	1.505
1.104	0.734	0.8817	0.9763	1.03	0	0	0	0	1.111
0.4189	0.734	0.8817	0.5353	0.3087	0	1.599	0	0	1.111

2. Determining Significant Characteristics

The data is now in a matrix format to which regression can be applied. Next we will decide which characteristics are the most important statistically, or which ones were statistically the most influential for judging ship capability in the opinions of the experts. This can be accomplished by stepwise regression. One way to do it is to regress one X variable, and add X variables one at a time. If the added variable has an acceptable t value it is kept; otherwise another is tried. Once an X variable has been selected and added it may be dropped if subsequently its t value becomes unacceptable.

To decide upon the first variable on which to regress the matrix of correlations was checked. No variable was extremely correlated so each Xij was regressed against the Yi's and that with the highest t value (Xi7, SAM) was chosen. It was then regressed with each other X variable in sequence and the pair with the highest t (SAM and CIWS, Xi7 and Xi9) was retained. This pair was then regressed in sequence with each other X variable and the trio with the highest t value was retained--Xi5, Xi7, and Xi9--Sonar, SAM, and CIWS. Continuing similarly, Xi5, Xi6, Xi7, and Xi9 were retained, the new addition being ASW Helicopter. See Appendix F for this sequence of regressions.

When these 4 characteristics were next combined with the remaining variables 3 possible subsets of characteristics were elgible for retention:

1. Xi5, Xi6, Xi7, Xi9, Xi10.
2. Xi3, Xi5, Xi6, Xi7, Xi9.
3. Xi5, Xi6, Xi7, Xi8, Xi9.

The first set was rejected because the scale value for Xi10, AA Gunfire Rate, is almost identical in all ships. This is not to say that all possible AA Gunfire Rates were

nearly identical, but that almost all ships had an AA Gun, and they almost all had the same rate of fire. This is especially true for the prospective ships to which the functional relationship will be applied. If all platforms possess a nearly identical characteristic, then that characteristic will not help to differentiate capability. A look at table II will make this clear.

The choice between the other two characteristics subsets is more difficult. It basically involves a choice of what is more important in determining capability--Xi3 or Xi8, ASW Missile or SSM. It seemed reasonable to try and work with both subsets, suggest combinations for regression that involved the different characteristics, and see which satisfied our equation criteria the best. Obviously all are important; we need to examine the way in which they interact in their contribution to capability. Numerous combinations were tried; some of the more interesting ones are presented here.

1. Xi5, Xi6, Xi7, Xi8, Xi9;

2. Xi3, Xi5, Xi6, Xi7, Xi9. These first two combinations do not attempt to suggest an interaction between the variables, but only examine the tradeoffs between SSMs and ASW missiles.

3. Xi5, Xi6, (Xi7 + Xi9), Xi8. This combination suggests an additive relationship between SAM and CIWS, considering the two as a defensive unit.

4. Xi5, Xi6, (Xi7 + Xi7(Xi9)), Xi8. Again the combination implies a SAM-CIWS interaction, but CIWS is not considered to contribute to Surface to Air (SA) defense except with SAM.

5. $(Xi5 + Xi5^{(Xi3)})$, Xi6, $(Xi7 + Xi7^{(Xi9)})$, Xi9. Here we have no SSM; the same SA defense combination as before except that CIWS is also considered individually; a sonar-ASW missile interaction; and the ASW Helicopter.

6. $(Xi5 + Xi5^{(Xi3)})$, Xi6, $(Xi7 + Xi7^{(Xi9)} + Xi9)$, Xi8. This time we consider the SSM and ASW Helicopter individually. The same Sonar-ASW missile relationship is postulated, as well as a heavier emphasis on SA defense. In this case the SAM and CIWS effects are additive as well as exponential.

7. Xi5, Xi6, $(Xi7 + Xi7^{(Xi9)} + Xi9)$, Xi8. In this instance the ASW missile is neglected and the ASW equipment considered individually.

8. $(Xi5 + Xi5^{(Xi6)})$, Xi6, $(Xi7 + Xi7^{(Xi9)} + Xi9)$, Xi8. The ASW missile is still neglected and the Sonar and Helicopter together have a synergistic effect although the Helicopter is also considered individually.

9. $(Xi5 + Xi5^{(Xi3)} + Xi6)$, $(Xi7 + Xi7^{(Xi9)} + Xi9)$, Xi8. This combination considers 3 weapon units: ASW, SA defense, and anti-surface offense. In the ASW unit, Sonar and the Helicopter are additive whereas the worth of the ASW missile is related to the Sonar. SA defense and anti-surface potential are considered as before.

Note that in none of these combinations are characteristics weighted by multiplication, or reciprocals, or other transformations. The judges assigned the weights to each characteristic so it would not be appropriate to change them individually. Interaction or relationship between the characteristics was not judged though, so it may rightly be postulated. Complete regression output for the 9 candidates can be found in Appendix G; selected output is displayed below.

An examination of selected regression output from these candidate combinations reveals that all have generous R^2 and F values. We can therefore confine our analysis of choice to other criteria. Candidate no. 2 although desirable in all other aspects, can be rejected because Xi3, the ASW missile, is multiplied by a negative coefficient. The field of candidates must be narrowed further. Keeping in mind our desire for the lowest possible SE, we might retain only the combinations with SEs of less than 0.18. This leaves the four candidate combinations of no.'s 4,6,7,and 9. The MSEs for these four are all attractive and do not add significant information so they will not be addressed further. The remaining statistical bases for judging these candidates are then in general SEs, t-values, residuals, and coefficients. Some of the regression output for the four combinations follows.

3. Candidate Analysis

a. General

Note that only combinations 6 and 9 contain Xi3 the ASW missile. Thus they might seem more appealing than the other two combinations which do not consider this weapon. An additional attractive quality of no. 9 is the fact that it has 8 degrees of freedom as opposed to 7 for the others. It also groups the weapon characteristics into 3 neat categories of ASW, SA defense, and Anti-Surface.

b. Standard Error

The lowest SE belonged to no. 7, at .1348. Highest SE was .1690 from no. 4.

c. t-Values

For all candidates t-values are acceptable. In examining the t-values for each candidate though, the information in Table III will be helpful. Absolute values are used to compute the data in the table. Here no. 7 dominates all others.

TABLE III

Selected Regression Output

t-Values

Candidate number	Mean	Median	Maximum	Minumum
4	10.299	7.6115	19.5861	6.6648
6	9.291	6.8648	20.3958	5.1680
7	11.602	8.3779	24.6514	7.9835
9	10.211	6.0627	20.3193	5.0521

Standard Error

Candidate number-->	4	6	7	9
	.1690	.1636	.1348	.1649

Residuals

Candidate number	Maximum	Balance	Median	Patternless
4	.2832	-8 +5	.0942	yes
6	.2872	-6 +6	.0820	no
7	.1968	-6 +6	.0437	yes
9	.2765	-5 +7	.0701	no

d. Residuals

An inadequacy of both candidates 9 and 6 are their residuals which show a generally steady decrease in absolute value as Yi increases. Residuals for both 4 and 7 are relatively patternless. The lowest maximum deviation can be found in no. 7, at .197. The highest maximum is .287 from combination 6, which also had perfectly 'balanced' residuals: six overestimate Yi and six underestimate Yi. Candidate combination 4 contains the most 'imbalanced' residuals with 8 that overestimate Yi and 4 that underestimate.

Because combination 7 has the lowest SE, highest t, lowest maximum deviation, and relatively patternless residuals, it appears we have found a plausible combination of characteristics. However: we should remember our goal is to accurately capture the judgement of the experts so it would be appropriate to look at how this combination numerically treats the weapon characteristics interaction. Model capabilities are listed here next to the judged values. A visual comparison shows the rank order did not change significantly, and, as another way to guage the fit of the model, per cent deviations of the residuals from the judged values were calculated and yielded a median of 6.88%, and a mean less than 2% higher. This might then be considered a plausible model to describe the functional relationship between ship capability and characteristics:

Capability = -.9736 + (1.0703 x Sonar Type) + (.4277 x ASW Helicopter) + (.5238 x (SAM + $SAM^{(CIWS)}$ + CIWS)) + (.4894 x SSM).

TABLE IV

Judged vs Model Ship Capabilities

Ship	Judged Capability	Model Capability
KARA	4.34	4.38
KRIVAK I	.969	.815
KASHIN	.546	.510
KRESTA II	1.69	1.72
KYNDA	1.38	1.41
HARUNA	1.23	1.22
DINA	2.79	2.59
TAKATSUKI	.723	.653
TACHIKAZE	.687	.718
HATSUYUKI	1.54	1.69
YAMAGUMO	.478	.652
AMATSUKAZI	.732	.718

V. MODEL APPLICATION AND DISCUSSION

A. GENERAL

A functional relationship has now been found linking ship capability to ship characteristics. Now it will be applied to a group of ships whose characteristics are known but whose capabilities are not. Eight ship types were selected from the Soviet Pacific Fleet and the Japanese Maritime Self Defense Force. These ship types represent the majority of the major surface combatants in both fleets [Ref. 3]. All 8 fall into 6 categories according to their characteristics. Table V shows each ship and its scale values for the characteristics in our functional relationship.

TABLE V

'Augment' Ship Types and Characteristics

Ship Types	Characteristics				
	Sonar	Helo	SAM	SSM	CIWS
KRESTA I	.3087	--	1.202	.773	.9354
KRIVAK II	1.03	--	.6507	--	--
GRISHA I	1.03	--	.3108	--	--
MIRKA II, ISUZU, MINEGUMO--	1.03	--	--	--	--
SHIRANE	3.146	3.142	.7679	--	1.069
ISHIKARI	.3087	--	--	1.478	--

A plot of the resulting capabilities as determined by application of the functional relationship is included here as Figure 1. Appendix H contains the mechanics of model application to the ship types.

B. DISCUSSION OF RESULTS

There are 20 ships' capabilities plotted in Figure 1--the 12 original 'sample' ships, and 8 'augments' to which the relationship was applied. Figure 1 is revealing in several ways. First it may lend evidence to support or reject our model. Second, from it one may postulate what drives the results. Further we might determine the sensitivity of overall capability to characteristics changes.

Of the 20 total ships 9 are Soviet and 11 are Japanese. Capability values range from 5.09 (SHIRANE) to .51 (KASHIN) with the median at 1.315. A look at the ships closest to median capability may be instructive. KYNDA at 1.41, is a powerful anti-surface warfare weapon with the most potent SSMs and a good SA defense consisting of SAMs and a CIWS. HARUNA on the other hand, at 1.22, has no credible SA defense at all nor any SSMs. What it does have is 3 SH-3 ASW Helicopters. It is fairly undisputed that a submarine will find it almost impossible to evade 2 or more dipping sonar-equipped ASW helicopters (as these are) once it is detected, so this may lend validity to our model. Now look at KRESTA II at 1.72 and KRESTA I at 1.62. The ASW platform KRESTA II has a helicopter (.5439) and powerful SA defense (SAM, 1.594; CIWS, .9354) but no SSMs, whereas KRESTA I, an anti-surface unit, has no helo, but it does have a good SA defense (SAM, 1.202; CIWS, .9354) and SSM (.773). The SSM on KRESTA I and single helicopter on KRESTA II appear to 'cancel each other out,' and the extra capability afforded by KRESTA II's SAM seem to make it a bit more powerful than KRESTA I. This result appears reasonable and again adds validity to our model.

Sonars are also quite influential. A ship with a good sonar system and little SA defense is, by this model, considered more capable than a ship with a high quality SA

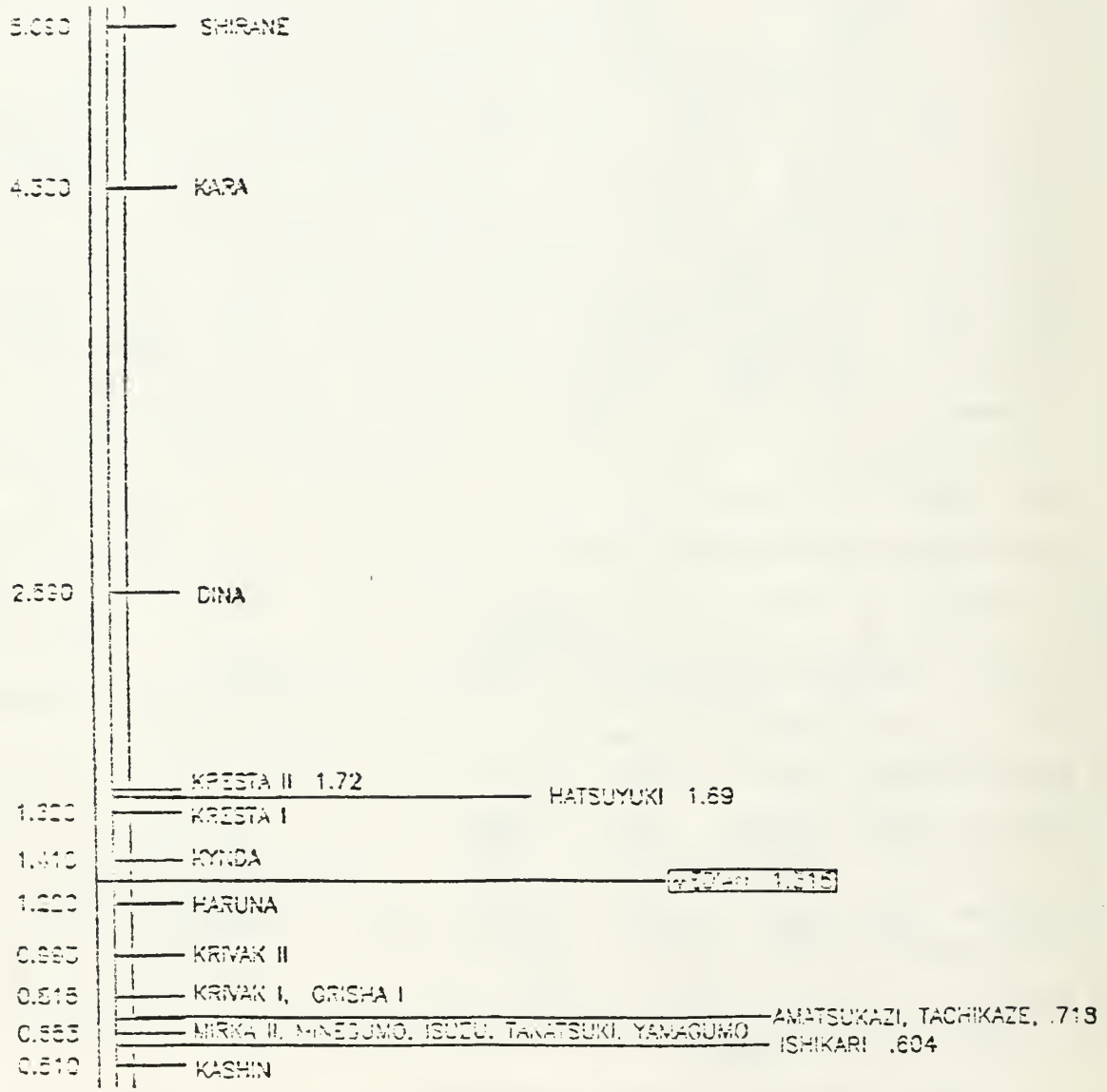


Figure 5.1 Capabilities

defense and only a hull sonar. For example, compare MINEGUMO and KASHIN. MINEGUMO's hull and variable depth sonars override KASHIN's hull sonar and 2 SA-N-1 SAMs. The highest ranked ship is SHIRANE, an ASW platform. Its 3 helicopters and complete sonar suite (but relatively poor SAM) dominate KARA and its top-of-the-line SAMs, good sonar system and single helicopter. It appears the multiple helicopters provide the difference in capability. To be fair it should be noted that no sample ship had all 3 sonar types, so we are using our model in the case of SHIRANE to extrapolate beyond the data in a sense. Also, the variance of prediction error for this ship (appendix H) is roughly 17% as compared to about 2.5% for the others. Nevertheless the result appears consistent with the other scale values. In fact 7 of the 8 most capable ships have ASW helicopters.

Another interesting observation is that 5/6 of the ships that have Helicopters also have ASW missiles; perhaps the ASW Missile characteristic, important but not significant in our functional relationship, is indirectly accounted for by the ASW Helicopter characteristic.

C. RECOMMENDATIONS

It is notable the sonar and ASW helicipters have figured so prominently in the model because both are detection systems. Since electronic intelligence gathering or countering systems were not considered in this study it would be fruitful to examine this area of detection and explore how it might affect the weapons systems and overall capability. An additional area that needs exploration is the effect on capability of command and control characteristics such as automation or data links. The lack of attention to detection systems is seen as the main limitation to the utility of this particular study. A limitation of the methodology

in general is the large number of comparisons to be made in the constant sum method of scaling. The maximum length of the questionaire depends on the respondent and how much personal committment he has to the survey originator or the project. It would be wise to carefully select the number of instances to be scaled or the experts.

A follow on study to this project could determine how total force capability is related to the ships it encompasses, enabling direct force on force comparisons, or, individual ship characteristics capabilities could be studied in further detail to derive relationships among their components. Studies of this sort could be used profitably in weapons acquisition or arms transfers to optimize capability or cost effectiveness, or they could also be used to evaluate possible weapons configurations for unbuilt systems.

The next chapter will summarize the most important points of this study.

VI. SUMMARY

This study has presented a method for finding a functional relationship between system capability and system characteristics; here, surface combatant warfare capability and ship characteristics. Ten characteristics were picked, and 12 ships from the Soviet Pacific Fleet and Japanese Maritime Self Defense Force were selected. Using expert opinion and the constant sum method of scaling the 10 ship characteristics were scaled, then so were the 12 ships. Multiple regression was used to specify which characteristics were most significant in determining ship capability, and then to find a relationship or equation linking ship capability and ship characteristics. The result was the following equation:

Capability = -.9736 + (1.0703 x Sonar Type) + (.4277 x ASW Helicopter) + (.5238 x SAM + SAM^{CIWS} + CIWS)).

It was then applied to 8 other ships from the same fleets and observations were made comparing the 20 total combatants on the basis of their capability and the significance of individual characteristics. ASW systems appeared to have the most influence in determining warfare capability, and multiple helicopters in particular were most influential.

APPENDIX A

SURFACE COMBATANT CHARACTERISTICS STUDY

A study is being made of various capability measures for some surface combatants and weapons systems. Judgements reflecting your expertise are solicited. For a copy of final results please indicate your SMC #. **THANK YOU VERY MUCH FOR YOUR TIME.**

Listed below are 12 ships, and several weapons systems. You will be asked to rate them relative to each other based on the amount of warfare capability they contribute in the following scenario:

Surface, subsurface conventional warfare in Sea of Japan and Sea of Okhotsk between Soviet and Japanese Naval forces. Both forces conduct sea denial missions; however, ASW and AAW are expected to dominate the action. Platforms possibly present include attack, cruise missile, and ballistic missile submarines, land based fighter and attack aircraft, and surface combatants. No logistics ships are required due to geographical proximity to support bases. No sea-based aviation other than ASW helos.

For each lettered category, please split 100 points within each pair listed, assigning a higher number to the item you think contributes more warfare capability. For example, if you think '8 Harpoon missiles' contributes much more capability than '4 SS-N-3Bs' in this scenario, you might split the 100 points as follows:

8 Harpoon missiles	80	4 SS-N-3Bs	20

or if you thought them to contribute equally:

8 Harpoon missiles	50	4 SS-N-3Bs	50

Omit pairs you feel unable to rate.

A. Surface to Surface Missile System

Candidates:

SS-N-3B: 250nm range, 1000kg warhead, inertial/active terminal homing.

SS-N-2C: 45nm, 500 kg, radar/IR terminal.

Harpoon: 60nm, 227kg, inertial/ active terminal.

8 SS-N-3B _____	4 SS-N-2C _____
8 SS-N-3B _____	8 Harpoon _____
8 SS-N-3B _____	4 SS-N-3B _____
8 Harpoon _____	4 SS-N-2C _____
8 Harpoon _____	4 SS-N-3B _____
4 SS-N-2C _____	4 SS-N-3B _____

B. Close-in Weapons Systems; Guns

Candidates:

Vulcan Phalanx: 20 mm, 3000 rounds/min.,integral director.

ADMG 630: 30 mm, 3000 r/min., separate director, one per two mounts.

4 ADMG 630 _____	2 Vulcan Phalanx _____

C. Ship Displacement

displacement (tons)	
< 3500 _____	3501-5000 _____
< 3500 _____	> 5000 _____
> 5000 _____	3501-5000 _____

year launched	
before 1965 _____	'65-'75 _____
before 1965 _____	'76-'85 _____
'65-'75 _____	'76-'85 _____

D. General Purpose Anti-Aircraft Guns (<77mm)

firing rate (rounds/min/mount)			
< 20	_____	21-75	_____
< 20	_____	> 75	_____
> 75	_____	21-75	_____

E. Surface to Air Missile System

Candidates:

SA-N-1: Twin launcher, 20km range, semi-active guidance.
SA-N-3: Twin, 30km, semi-active.
SA-N-4: Twin, 9km, semi-active.
SM-1 MR: Single, 50km, semi-active.
Sea Sparrow: 8 cell box, 16km, semi active.

2 SA-N-3&2 SA-N-4	____	1 Sea Sp.	____
2 SA-N-3&2 SA-N-4	____	2 SA-N-3	____
2 SA-N-3&2 SA-N-4	____	2 SA-N-1	____
2 SA-N-3&2 SA-N-4	____	1 SA-N-1	____
2 SA-N-3	____	2 SA-N-1	____
2 SA-N-3	____	1 SA-N-1	____
2 SA-N-3	____	1 SA-N-4	____
2 SA-N-3	____	2 SA-N-4	____
2 SA-N-3&2 SA-N-4	____	2 SA-N-4	____
2 SA-N-3&2 SA-N-4	____	2 SA-N-4	____
2 SA-N-3&2 SA-N-4	____	1 SM-1 MR	____
2 SA-N-3	____	1 SM-1 MR	____
2 SA-N-1	____	1 SA-N-1	____
2 SA-N-1	____	1 SA-N-4	____
1 Sea Sparrow	____	2 SA-N-3	____
1 Sea Sparrow	____	2 SA-N-1	____
1 Sea Sparrow	____	1 SA-N-1	____
1 Sea Sparrow	____	1 SA-N-4	____
1 Sea Sparrow	____	2 SA-N-4	____

1 Sea Sparrow	____	1 SM-1 MR	____
1 SA-N-4	____	2 SA-N-4	____
2 SA-N-1	____	2 SA-N-4	____
2 SA-N-1	____	1 SM-1 MR	____
1 SA-N-1	____	1 SA-N-4	____
1 SA-N-1	____	2 SA-N-4	____
1 SA-N-1	____	1 SM-1 MR	____
2 SA-N-4	____	1 SM-1 MR	____
1 SA-N-4	____	1 SM-1 MR	____

F. Anti-Submarine Warfare Systems

Comments:

All helicopters have dipping sonars.

SS-N-14: 30nm range, limited surface capability.

ASROC: 14nm range.

'ASW Rockets' are weapons such as RBU-6000, Hedgehog, Bofors, etc.

ASW Helicopters

1 Hormone A	____	1 SH-3B	____
1 Hormone A	____	3 SH-3B	____
1 SH-3B	____	3 SH-3B	____

ASW missiles

8 SS-N-14	____	4 SS-N-14	____
8 SS-N-14	____	8 ASROC	____
4 SS-N-14	____	8 ASROC	____

sonar types and combinations

hull, VDS, towed	____	hull	____
hull, VDS, towed	____	hull, VDS	____
hull, VDS	____	hull	____

Miscellaneous ASW Weapons

torpedoes	____	torpedoes, ASW rockets	_____
torps, d.c., ASW rockets	____	torps, ASW rockets	_____
torps, d.c., ASW rockets	____	torps	_____

G. Ships

Information on particular ships follows.

Kresta II___ Kynda ___
Kresta II___ Dina ___
Kresta II___ Kara ___
Kresta II___ Kashin ___
Kresta II___ Hatsuyuki ___
Kresta II___ Amatsukazi___

Kynda ___ Dina ___
Kynda ___ Kara ___
Kynda ___ Kashin ___
Kynda ___ Hatsuyuki ___
Kynda ___ Amatsukazi___
Haruna ___ Takatsuki ___
Haruna ___ Krivak I ___

Haruna ___ Tachikazi ___
Haruna ___ Yamagumo ___
Dina ___ Takatsuki ___
Dina ___ Krivak I ___
Dina ___ Tachikazi ___
Dina ___ Yamagumo ___

Takatsuki___ Kara ___
Takatsuki___ Kashin ___
Takatsuki___ Hatsuyuki ___
Takatsuki___ Amatsukazi___
Kara ___ Kashin ___
Kara ___ Hatsuyuki ___
Kara ___ Amatsukazi___

Krivak I ___ Tachikazi ___
Krivak I ___ Yamagumo ___
Kashin ___ Tachikazi ___
Kashin ___ Yamagumo ___

Kresta II___ Haruna ___
Kresta II___ Takatsuki ___
Kresta II___ Krivak I ___
Kresta II___ Tachikazi ___
Kresta II___ Yamagumo ___
Kynda ___ Haruna ___

Kynda ___ Takatsuki ___
Kynda ___ Krivak I ___
Kynda ___ Tachikazi ___
Kynda ___ Yamagumo ___
Haruna ___ Dina ___
Haruna ___ Kara ___
Haruna ___ Kashin ___

Haruna ___ Hatsuyuki ___
Haruna ___ Amatsukazi___
Dina ___ Kara ___
Dina ___ Kashin ___
Dina ___ Hatsuyuki ___
Dina ___ Amatsukazi___

Takatsuki___ Krivak I ___
Takatsuki___ Tachikaze ___
Takatsuki___ Yamagumo ___
Kara ___ Krivak I ___
Kara ___ Tachikazi ___
Kara ___ Yamagumo ___
Krivak I ___ Kashin ___

Krivak I ___ Hatsuyuki ___
Krivak I ___ Amatsukazi___
Kashin ___ Hatsuyuki ___
Kashin ___ Amatsukazi___

Tachikazi___ Hatsuyuki ___
Tachikazi___ Amatsukazi___
Hatsuyuki___ Amatsukazi___

Tachikazi___ Yamagumo ___
Hatsuyuki___ Yamagumo ___
Yamagumo ___ Amatsukazi___

TABLE VI

Ships

Ship	Year & Displ.	ASW missile	Other ASW	Sonar/ Helo	SAM	SSM	CIWS	Gun rpm
Kresta II	71 6200	8 SS-N-14	2 RBU6000 2 RBU1000 torps	hull 1 horm A	2 SA-N-3		4 ADMG	150
Kynda	62 4400		2 RBU6000 torps	hull	1 SA-N-1	8 SS-N-3	4 ADMG	45
Haruna	72 4700	8 ASROC	torps	hull 3 SH-3				
Dina	84 4450		torps	hull 1 SH-3	1 SM-1	8 Harp	2 Vul- Phlx	
Takatsuki	68 3200	8 ASROC	1 Bofors torps	hull VDS				
Kara	74 8200	8 SS-N-14	2 RBU6000 2 RBU1000 torps	hull VDS 1 Horm	2 SA-N-3 2 SA-N-4		4 ADMG	45

Table 6
Ships (cont'd.)

Ship	Year & Displ.	ASW missile	Other ASW	Sonar/ Helo	SAM	SSM	CIWS	Gun rpm
Krivak I	75 3100	4 SS-N-14	2 RBU6000 torps	hull VDS	2 SA-N-4			45
Kashin	68 3750		2 RBU6000 2 RBU1000 torps	hull	2 SA-N-1			45
Tachikaze	77 3850	8 ASROC	torps	hull	1 SM-1			
Hatsuyuki	80 2950	8 ASROC	torps	hull 1 SH-3	1 Sea Sparrow	8 Harp	2 Vul-Phlx	85
Yamagumo	71 2100	8 ASROC	1 Bofors torps	hull VDS				45
Amatsukazi	63 3050	8 ASROC	1 Hedge-hog torps	hull	1 SM-1			45

APPENDIX B

SURFACE TO AIR MISSILE SYSTEM DATA

Surface to Air Missile System

Candidates:

SA-N-1: Twin launcher, 20km range, semi-active guidance.
SA-N-3: Twin, 30km, semi-active.
SA-N-4: Twin, 9km, semi-active.
SM-1 MR: Single, 50km, semi-active.
Sea Sparrow: 8 cell box, 16km, semi active.

X1: 2 SA-N-3 & 2 SA-N-4
X2: 1 Sea Sparrow
X3: 2 SA-N-3
X4: 2 SA-N-1
X5: 1 SA-N-1
X6: 1 SA-N-4
X7: 2 SA-N-4
X8: 1 SM-1MR

The A Matrix for Surface to Air Missile

i
|
j-->

	X1	X2	X3	X4	X5	X6	X7	X8
X1	50	26	25	23.5	13	6.7	15.5	37.8
X2	74	50	67	59	49	33.7	46	70.5
X3	75	33	50	37	27.5	17.5	27.5	47.5
X4	76.5	41	63	50	22.7	26.5	31.5	55
X5	87	51	72.5	77.3	50	30.5	46.5	72
X6	93.3	66.3	82.5	73.5	69.5	50	77.3	80.5
X7	84.5	54	72.5	68.5	49.4	22.6	50	71.5
X8	62.2	29.5	52.5	45	27	16.5	27	50

The W Matrix for Surface to Air Missile

	X1	X2	X3	X4	X5	X6	X7	X8
X1	1	.351	.333	.307	.149	.072	.183	.608
X2	2.85	1	2.03	1.44	.961	.508	.852	2.39
X3	3	.493	1	.587	.379	.212	.379	.905
X4	3.26	.695	1.7	1	.294	.361	.46	1.22
X5	6.69	1.04	2.64	3.41	1	.439	.869	2.57
X6	13.9	1.97	4.71	2.77	2.28	1	3.41	4.13
X7	5.45	1.17	2.64	2.17	1.15	.294	1	2.51
X8	1.65	.418	1.11	.818	.389	.242	.399	1

The Scale values for Surface to Air Missile

Surface to Air Missile System							
2 SA-N-3	1 Sea	2	2	1	1	2	1
2 SA-N-4	Sparrow	SA-N-3	SA-N-1	SA-N-1	SA-N-4	SA-N-4	SM-1MR
3.514	.7679	1.594	1.202	.5998	.3108	.6507	1.599

APPENDIX C

A MATRICES, W MATRICES, AND SCALE VALUES

Following are A Matrices, W Matrices, and Scale Values for all characteristics other than Surface to Air Missiles.

Surface to Surface Missile

X1: 8 SS-N-3B X2: 4 SS-N-2C

X3: 8 Harpoon X4: 4 SS-N-3B

The A Matrix

	X1	X2	X3	X4
X1	50	29.3	41.1	20.8
X2	80.9	50	79.4	70.7
X3	58.9	20.6	50	36.1
X4	79.2	19.1	63.9	50

W Matrix

	X1	X2	X3	X4
X1	1	0.415	0.698	0.262
X2	2.41	1	3.86	2.41
X3	1.43	0.259	1	0.565
X4	3.81	0.415	1.77	1

Scale Values

Surface to Surface Missile			
8 SS-N-3B	4 SS-N-2C	8 Harpoon	4 SS-N-3B
1.9	0.46	1.48	0.773

Close-In Weapon System

X1: 4 ADMG 630 X2: 2 Vulcan Phalanx

The A Matrix

	X1	X2
X1	50	53.3
X2	46.7	50

The W Matrix

	X1	X2
X1	1	1.14
X2	0.875	1

Scale Values

Close In Weapon System	
4 ADMG 630	2 Vulcan Phalanx
0.935	1.07

Ship Displacement

X1: < 3500 tons X2: 3500-5000 tons X3: > 5000 tons

The A Matrix

	X1	X2	X3
X1	50	60.6	62.2
X2	39.4	50	55.6
X3	37.8	44.4	50

The W Matrix

	X1	X2	X3
X1	1	1.54	1.65
X2	0.651	1	1.25

Close-In Weapon

X1: 4 ADMG 630 X2: 2 Vulc

The A Matrix

	X1	X2
X1	50	53.3
X2	46.7	50

The W Matrix

	X1	X2
X1	1	1.14
X2	0.875	1

Scale Values

Close In Weapon
4 ADMG 630
0.935

Ship Displacem

X1: < 3500 tons X2: 3500-5000

X3	37.8	44.4	50

The W Matrix

	X1	X2	X3
X1	1	1.54	1.65
X2	0.651	1	1.25

The A Matrix

	X1	X2	X3
X1	50	64.5	72
X2	35.5	50	57
X3	28	43	50

The W Matrix

	X1	X2	X3
X1	1	1.82	2.57
X1	0.55	1	1.33
X3	0.389	0.754	1

Scale Values

Anti-Aircraft Gunfire Rate		
< 20 rpm	21-75 rpm	> 75 rpm
0.598	1.11	1.5

ASW Helicopters

X1: 1 Hormone A X2: 1 SH-3 X3: 3 SH-3

The A Matrix

	X1	X2	X3
X1	50	56	83
X2	44	50	86.4
X3	17	13.6	50

The W Matrix

	X1	X2	X3
X1	1	1.27	4.88
X1	0.786	1	6.35
X3	0.205	0.157	1

The A Matrix

	X1	X2	X3
X1	50	64.5	72
X2	35.5	50	57
X3	28	43	50

The W Matrix

	X1	X2	X3
X1	1	1.82	2.57
X1	0.55	1	1.33
X3	0.389	0.754	1

Scale Values

Anti-Aircraft Gunfire Rate		
< 20 rpm	21-75 rpm	> 75 rpm
0.598	1.11	1.5

ASW Helicopters

X1: 1 Hormone A X2: 1 SH-3 X3: 3 SH-3

The A Matrix

	X1	X2	X3
X1	50	56	83
X2	44	50	86.4
X3	17	13.6	50

The W Matrix

	X1	X2	X3
X1	1	1.27	4.88
X1	0.786	1	6.35
X3	0.205	0.157	1

depth charges

The A Matrix

	X1	X2	X3
X1	50	62.8	79.4
X2	37.2	50	64.4
X3	20.6	35.6	50

The W Matrix

	X1	X2	X3
X1	1	1.69	3.86
X1	0.593	1	1.81
X3	0.259	0.552	1

Scale Values

Miscellaneous ASW Weapons		
Torpedoes	Torpedoes & ASW Rockets	Torpedoes, ASW Rockets, depth charges
0.535	0.976	1.91

Sonar Type

X1: Hull, VDS & Towed Array X2: Hull & VDS X3: Hull Only

The A Matrix

	X1	X2	X3
X1	50	26.1	8.33
X2	73.9	50	24.4
X3	91.7	75.6	50

The W Matrix

	X1	X2	X3
X1	1	0.353	0.0909
X1	2.83	1	0.324
X3	11	3.09	1

Scale Values

Sonar Type		
Hull, VDS, & Towed Array	Hull & VDS	Hull
3.15	1.03	0.309

APPENDIX D

SCALE VALUES FOR SAMPLE SHIPS AND CHARACTERISTICS

Surface to Surface Missile			
8 SS-N-3B	4 SS-N-2c	8 Harpoon	4 SS-N-3B
1.905	.4595	1.478	.773

Close In Weapon System	
4 ADMG 630	2 Vulcan Phalanx
.935	1.07

Ship Displacement (tons)		
< 3500	35-5000	> 5000
.734	1.071	1.272

Year Launched		
< 1965	65-75	>75
.4189	1.104	2.162

Anti-Aircraft Gunfire Rate (rounds/min)		
< 20	21-75	> 75
.5982	1.111	1.505

Surface to Air Missile System							
2 SA-N-3	1 Sea	2	2	1	1	2	1
2 SA-N-4	Sparrow	SA-N-3	SA-N-1	SA-N-1	SA-N-4	SA-N-4	SM-1MR
3.514	.7679	1.594	1.202	.5998	.3108	.6507	1.599

Appendix (cont.)

Helicopter			ASW Missile		
1	1	3	8	4	8
Hormone A	SH-3	SH-3	SS-N-14	SS-N-14	ASROC
.5439	.5851	3.142	1.805	.6284	.8817

Sonar Type			Miscellaneous ASW Weapons		
hull	hull,VDS, & towed array	hull & VDS	torpedoes	torps & ASW rockets	torps, rockets & depth charges
.3087	3.146	1.03	.5353	.9763	1.913

Ships			
Kresta II	Kynda	Haruna	Dina
1.69	1.38	1.23	2.79
Takatsuki	Kara	Krivak I	Kashin
.723	4.34	.969	.546
Tachikazi	Hatsuyuki	Yamagumo	Amatsukazi
.687	1.54	.478	.732

APPENDIX E

APL FUNCTIONS USED

```
      REGRESSHOW

SYNTAX:  Z←Y REGRESS X
PARAMETER:
          ΔINTERCEPT- DETERMINES WHETHER OR NOT AN INTERCEPT TERM
          IS TO BE INCLUDED.  ΔINTERCEPT=1 GIVES AN INTERCEPT
          TERM, AND ΔINTERCEPT=0 GIVES NO INTERCEPT. (DEFAULT IS
          1.)
GROUP:  RELATIONS
SUBPROGRAMS:  FMT AND SCAT
DESCRIPTION:  REGRESS DOES A MULTIPLE REGRESSION ANALYSIS
RELATING THE DEPENDENT VARIABLE Y TO A SET OF CARRIERS X. THE
LEFT ARGUMENT Y IS A VECTOR OF SIZE N. THE RIGHT ARGUMENT X IS
AN N BY K MATRIX CONSISTING OF N OBSERVATIONS ON EACH OF K
VARIABLES OR A VECTOR OF SIZE N IF K=1. OUTPUT CONSISTS OF AN
ANOVA TABLE, R-SQUARE, STD. ERROR, REGRESSION COEFFICIENTS (THE
FIRST COEFFICIENT IS THE CONSTANT TERM IF ΔINTERCEPT=1.),
T-STATISTICS, VARIANCE-COVARIANCE MATRIX, DURBIN-WATSON
STATISTIC, AND A VECTOR OF PREDICTED Y VALUES AND RESIDUALS.
THERE IS AN OPTION THAT ALLOWS THE USER TO INPUT A VECTOR OF X
VALUES AND USE THE REGRESSION EQUATION TO FORECAST Y VALUES. THE
USER CAN ALSO OBTAIN A SCATTER PLOT OF THE RESIDUALS. WHEN
EXECUTION TERMINATES, THE PREDICTED Y VALUES AND THE RESIDUALS
RESIDE IN THE N BY 2 MATRIX Z.


      CORRELATIONHOW

SYNTAX:  R←CORRELATION W
GROUP:  STATS
SUBPROGRAM:  FMT
DESCRIPTION:  CORRELATION DETERMINES THE SIMPLE PEARSON PRODUCT
MOMENT CORRELATIONS BETWEEN EACH PAIR OF VARIABLES REPRESENTED BY
THE C COLUMNS OF W.  THE OUTPUT IS A C BY C CORRELATION MATRIX.
```

```
      ∇REGRESS[□]∇

      ∇ Z←Y REGRESS X;N;K;C;XPXINV;XPY;BETA;RSS;TSS;S2;ESS;WID;DEP
[1]   X←(2↑(⍴X),1)⍴X
[2]   X←(0,1-⍙INTERCEPT)↓1,X
[3]   XPXINV←⌹(⍉X)+.×X
[4]   BETA←XPXINV+.×XPY←(⍉X)+.×Y
[5]   RSS←((⍉BETA)+.×XPY)-C←((+⌿Y)*2)÷N←⍴,Y
[6]   ESS←(TSS←((⍉Y)+.×Y)-C)-RSS
[7]   S2←,ESS÷(N-1)-K←(⍴,BETA)-⍙INTERCEPT
[8]   CR
[9]   '                                ANOVA'
[10]  CH←'SOURCE,DF,SUM SQUARES,MEAN SQUARE,F-RATIO'
[11]  ⍞←CH
[12]  '□REGRESSION□,I4,BE16.4' FMT(K),(,RSS),(,RSS÷K),(,RSS÷K)÷S2
[13]  CH←''
[14]  '□   RESIDUAL□,I4,BE16.4' FMT((N-1)-K),(,ESS),S2,0
[15]  '□TOTAL     □,I4,BE16.4' FMT(N-1),(,TSS),0,0
[16]  ' '
[17]  (⍞'R SQUARE:  '),⍕,RSS÷TSS
[18]  (⍞'STD ERROR: '),⍕,S2*0.5
[19]  CH←'COEFFICIENTS,T STATISTICS'
[20]  ⍞F15.4' FMT⍉(2,⍴,BETA)⍴(,BETA),(,BETA)÷(1 1 ⍉V←S2×XPXINV)*0.5
[21]  'DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?'
[22]  →A1×⍳'Y'≠1↑□
[23]  'VARIANCE-COVARIANCE MATRIX: ',CH←''
[24]  'E12.4' FMT V
[25]  A1:(⍞'DURBIN-WATSON: '),⍕(+⌿((1↓,C)-(¯1↓,C))*2)÷+⌿(,C←Y-X+.×BETA)*2
[26]  Z←⍉(2,N)⍴(,X+.×BETA),,C
[27]  B1:'DO YOU WANT TO FORECAST A VALUE FOR Y?'
[28]  →C1×⍳'Y'≠1↑□
[29]  (⍞'ENTER X VECTOR ('),(⍕K),⍞' VALUES)'
[30]  (⍞'FORECAST OF Y VALUE: '),⍕(C←(1-⍙INTERCEPT)↓1,□)+.×BETA
[31]  (⍞'VARIANCE OF FORECAST ERROR: '),⍕S2×1+C+.×XPXINV+.×⍉C
[32]  →B1
[33]  C1:'DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?'
[34]  →0×⍳'N'=1↑□
[35]  DEP←0.5×WID←⌊/70,(⌈/((0.75×N),30))
[36]  SCAT Z
```

```
      ∇SCAT[□]∇

      ∇ W←SCAT Z;N;X;Y;C;R;U;S;L;I;J;K;UT;CL;G;D;B;A;O;V
[1]   →3×ι(2=+/2=N)∨(×/N)>+/N←ρZ
[2]   Z←⍉(2,ρZ)ρ(ιρZ),Z←,Z
[3]   Y←Z[;1+ιC←¯1+(ρZ)[2]]
[4]   R←ρZ←X←,Z[;1]
[5]   L←U←S←2ρ0
[6]   J←1+0×ρ(D←NDIVX,NDIVY),B←WID,DEF
[7]   UT←10*L10⌈CL←1E¯20+((U[J]←⌈/Z)-S[J]←⌊/Z)÷D[J]
[8]   S[J]←UT×⌊S[J]÷UT←UT[1↑⍋|CL-UT←(1 2 5)×UT]
[9]   U[J]←UT×⌈U[J]÷UT
[10]  L[J]←1+G×⌊(B[J]-1)÷G←(U[J]-S[J])÷UT
[11]  Z←,Y
[12]  →7×ι3)J←J+1
[13]  A←(⍬L)ρ0
[14]  X←1+⌊0.5+(L[1]-1)×(X-S[1])÷U[1]-S[1]
[15]  Y←1+⌊0.5+(L[2]-1)×(Y-S[2])÷U[2]-S[2]
[16]  I←1
[17]  →20×ι1<C
[18]  A[Y[I;1];X[I]]←10⊥A[Y[I;1];X[I]]+1
[19]  →18+6×R>(I←I+1)
[20]  J←1
[21]  D←0=V←A[Y[I;J];X[I]]
[22]  A[Y[I;J];X[I]]←(10×V)⊥K+1)+((K+1)×K=V)+(K←35-2×J)×D
[23]  →21×ιR≥I←I+1
[24]  →21×ιC≥J←J+I←1
[25]  O←(⍬∘A)⍳1⌈1+⌊0.5+(L-1)×S÷S-U
[26]  A[;O[1]]←A[;O[1]]+36×0=A[;O[1]]
[27]  A[O[2];]←A[O[2];]+35×0=A[O[2];]
[28]  W←' ∘23456789ABCDEFGHIJKLMNOPQRSTUVWXYZ'[1+⊖A]
[29]  (⍞'RANGE OF X: '),⍕S[1],U[1]
[30]  (⍞'RANGE OF Y: '),⍕S[2],U[2]
      ∇
      ∇
      ∇GMEEN[□]∇

      ∇ SJ←GMEEN COL
[1]   SJ←(×/COL)*1÷ρCOL
[2]   ⍝ GIVES SCALE VALUES BY FINDING GEOMETRIC MEANS OF W
        MATRIX COLUMNS
      ∇

      ∇CORRELATION[□]∇

      ∇ R←CORRELATION W;Z;C;S;CH;MEANS;VAR
[1]   C←(⍴Z)+.×Z←W-(ρW)ρ(MEANS←+⌿W)÷1↑ρ(¯2↑1,1,ρW)ρW←W+ρCH←''
[2]   R←'BF8.2' FMT(0,1ρS),[1](1ρS),C÷S∘.×S←(VARS←+⌿Z*2)*0.5
      ∇
      ∇AGE[□]∇

      ∇ AIJ←AGE V
[1]   AIJ←V÷(100-V)
[2]   ⍝ FINDS RECIPROCALS FOR W MATRIX
```

```
      ▽FMT[⎕]▽

       ▽ OL←F FMT R;S;W;⍺;G;X;T;K;J;M;Q;P;D;N;O;L;B;V;CH;H
[1]    N←⍴⍴R←,R←(1⌈¯2↑⍴R)⍴R
[2]    OL←((1=1↑M)↓ 1 0 ×M←M+2↑H←1(⍴CH←⎕UCS 13,',')⍴⍺←'0123456789.'
[3]    →E×⍳(N←0=N)∨V←1≥⍴S←,F
[4]   L0:→~⍳V∨(×F←4×Q←⍴K←⍴X←' ')∧≠/('A',O←'⎕')∈S
[5]    →(L0+(V←0=⍴S←J↓S)+⍳B←M[2]←1),L←-(⍳×B←0+.=K),P×~'A'∈K←K,(J←S⍳',')↑S
[6]    →E+×⍴S←'TEXT DELIMITER'
[7]    →L3-3××(⍴G←K=K←(K∈¯1↓⍺)/K)⌊W←⍴X←(⍴K←(K⍳0)↑K)↓(-(ΦK)⍳0)↓K
[8]   L:→(D←~1↑G←K∈⍺)/L3-2×(⍴K)≠W←1↑0←'XA'∈K←(~K∈' ,')/K
[9]    →L3×⍳(B≠+/G)∨×M[2]←10⊥1+-⍺⍳(B←1+G⍳0)↑K
[10]   →L3-ΦO,-(L←'EFI'∈K)/×W←10⊥1+-⍺⍳(1+G←B⍳'.')↑B←(1-(ΦG)⍳0)↑K
[11]   A←(1↓⍴X←((1⌈⍴⍺)↑(M[1]-H),W)↑⍺)ΦA
[12]  L3:→(HD×⍳H∧~'X'∈K),E-⍴X←-W.D←0⍴P←((M-H,0)×1,W)⍴X
[13]   →L4-1~1↑L,Q←1↓⍴R←(0 1 ×⍴P←R[;⍳M[2]←QLM[2]⌈Q×V∧D])↓R
[14]   P←P÷10*L←⌊10⍟|P+0=P
[15]   →L3×⍳0=J←+/B←('B'∈K)∨0=P←(L0.5+N×.P)÷N←10*D←10⊥1+-⍺⍳G↓B
[16]  L4:→(⍴1↓⍴L)/F-⍴⍴X←(1 0 ×⍴G←J⍴T\'¯')⍴J←J,O←∨/T←0)P←B/P
[17]   →(×L←(O⌈L×J←'Z'∈K)⌈.×~T←(T+0←1+L10⍟1⌈|P))>O+L←W-D+O+~2↓L)/L/F,F,I
[18]   →E+×⍴S←'FIELD WIDTH'
[19]   →L4+1+⍳((J[2]←L∨.(0)+O←1+10⌈.≤|L←(B/,L)+T←10=|P))W-D+O+3
[20]   T←~J←P[T/⍳1↑J]←L←⍴1⍴X←'E',¯1+0⍕'[J⍴2-×L],⍺[1+⍳(0⍴10)⊤|L]
[21]  F:→(J∨2≥Dx←~'T'∈K)/I,N←⍴X←⍺[11,1+⍳(D⍴10)⊤⌈N×1||P],X
[22]   D←,(-N)↑(D⌈.×⍳2+D]≠1↑⍺)∘.(D←⍳D-1
[23]   X←N⍴X,X[D/⍳⍴X←,X]←'
[24]  I:→(J←J∨0=+/O←0⌈L-O)/I+⍴D←⍴P←G,⍺[1+⍳(L⍴10)⊤L|P]
[25]   P←D⍴(,O←GΦO)\(,O←0∘.((-G)Φ⍳L+G←1↓⍴G)/,P
[26]   →HD-⍳J∨L←~'L'∈K,P[T/⍳D←1↑X←⍴P←P,X;]←'*'
[27]   P←X⍴(,ΦO)\(,O←~X↑~O)/,P
[28]   →(~H)/E-N←1,D←0⍴P←B←(D,X←W×1-2×L)↑P
[29]  HD:CH←(⍴K←(¯1↑D←0,(M[2]⌊⍴D)⍴D←(',⍳'=CH)/⍳⍴CH)⍴CH)ΦCH
[30]   D←,(M[2],X)↑ 0 ¯1 ↓(M[2],B)⍴(,ΦD∘.≤⍳B←1⌈/D←1↓D-¯1ΦD)\K
[31]   →(L0-V∧×Q),⍴OL←OL,((1=1↑M)↓M×1,W)⍴D,,P
[32]  E:K←'NO VALID E, I, OR F PHRASE'
[33]   (⍕'FMT PROBLEM      ',K),⍕(1,⍴S)⍴S
       ▽
```

APPENDIX F

REGRESSION SEQUENCE FOR CANDIDATE SELECTION

```
      XX

 1.1    1.27   1.8    0.976  1.03   0.544  3.51   0      0.935  1.11
 1.1    0.734  0.628  0.976  1.03   0      0.311  0      0      1.11
 1.1    1.07   0      0.976  0.309  0      1.2    0      0      1.11
 1.1    1.27   1.8    0.976  0.309  0.544  1.59   0      0.935  1.5
 0.419  1.07   0      0.976  0.309  0      0.6    1.9    0.935  1.11
 0.419  0.734  0      1.91   1.03   0      0      0      0      1.11
 1.1    1.07   0.882  0.535  0.309  3.14   0      0      0      1.11
 2.16   1.07   0      0.535  0.309  0.585  1.6    1.48   1.07   1.11
 1.1    0.734  0.882  0.976  1.03   0      0      0      0      1.11
 2.16   1.07   0.882  0.535  0.309  0      1.6    0      0      1.11
 2.16   0.734  0.882  0.535  0.309  0.585  0.768  1.48   1.07   1.5
 1.1    0.734  0.882  0.976  1.03   0      0      0      0      1.11
 0.419  0.734  0.882  0.535  0.309  0      1.6    0      0      1.11
      P

      YY

4.34 0.969 0.546 1.69 1.38 0.213 1.23 2.79 0.723 0.687 1.54
0.478 0.732

      YY REGRESS XX

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION  10        1.3849E1         1.3849E0          4.6144E1
  RESIDUAL   1        3.0013E-2        3.0013E-2
TOTAL       11        1.3879E1

R SQUARE:  0.99783757
STD ERROR: 0.17324116
   COEFFICIENTS    T STATISTICS
        -1.4201          -0.245
        -0.3214          -0.4981
         1.5291           0.4506
        -0.7376          -0.8746
        -2.0342          -0.6069
         2.6697           1.0553
         0.3637           1.4075
        -0.5878          -3.3122
        -0.1932          -0.4216
         1.4268           1.289
         1.0259           0.2181
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 2
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N
```

```
      CORRELATION XX

     1      2      3      4      5      6      7      8      9     10
1   1.00   0.05  -0.04  -0.51  -0.18   0.07   0.11   0.22   0.26   0.29
2   0.05   1.00   0.24   0.11  -0.33   0.28   0.62   0.01   0.45   0.08
3  -0.04   0.24   1.00   0.13   0.31   0.16   0.41  -0.52   0.12   0.43
4  -0.51   0.11   0.13   1.00   0.60  -0.41  -0.04  -0.22  -0.03  -0.08
5  -0.18  -0.33   0.31   0.60   1.00  -0.26  -0.08  -0.40  -0.26  -0.32
6   0.07   0.28   0.16  -0.41  -0.26   1.00  -0.16  -0.06   0.01   0.06
7   0.11   0.62   0.41  -0.04  -0.08  -0.16   1.00  -0.06   0.45   0.05
8   0.22   0.01  -0.52  -0.22  -0.40  -0.06  -0.06   1.00   0.71   0.21
9   0.26   0.45   0.12  -0.03  -0.26   0.01   0.45   0.71   1.00   0.54
10  0.29   0.08   0.43  -0.08  -0.32   0.06   0.05   0.21   0.54   1.00

      Z←YY REGRESS XX[;7]

                              ANOVA

     SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION    1        7.7615E0        7.7615E0          1.2687E1
  RESIDUAL   10      6.1176E00       6.1176E-1
TOTAL        11        1.3879E1

R SQUARE:  0.5592
STD ERROR: 0.7821
   COEFFICIENTS   T STATISTICS
         0.5474          1.6374
         0.8241          3.5619
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.481
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N


      Z←YY REGRESS XX[;7 9]

                              ANOVA

     SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION    2        1.0221E1        5.1105E0          1.2573E1
  RESIDUAL    9      3.6581E00       4.0646E-1
TOTAL        11        1.3879E1

R SQUARE:  0.7364
STD ERROR: 0.6375
   COEFFICIENTS   T STATISTICS
         0.3714          1.3183
         0.5877          2.7768
         1.0384          2.4599
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.254
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N
```

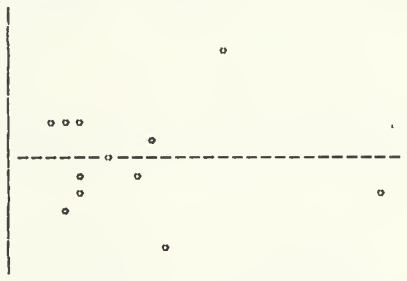
```
      Z←YY REGRESS XX[;5 7 9]

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   3        1.1532E1        3.8441E0          1.3104E1
  RESIDUAL   8       2.3468E00       2.9335E-1
TOTAL       11        1.3879E1

R SQUARE:  0.8309
STD ERROR: 0.5416
   COEFFICIENTS    T STATISTICS
         0.2443          0.6482
         1.0071          2.1145
         0.5711          3.1728
         1.2336          3.3313
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.256
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N


      Z←YY REGRESS XX[;5 6 7 9]

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3324E1        3.3310E0          4.2009E1
  RESIDUAL   7       5.5505E-1       7.9293E-2
TOTAL       11        1.3879E1

R SQUARE:  0.96
STD ERROR: 0.2816
   COEFFICIENTS    T STATISTICS
         0.7129          3.2499
         1.3293          5.1772
         0.4781          4.7536
         0.6516          6.8521
         1.2111          6.2885
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.959
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N


      Z←YY REGRESS XX[;3 5 6 7 9]

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   5        1.3783E1        2.7566E0          1.7229E2
  RESIDUAL   6       9.5998E-2       1.6000E-2
TOTAL       11        1.3879E1
```

```
R SQUARE:  0.9931
STD ERROR: 0.1265
   COEFFICIENTS    T STATISTICS
        ¯0.7333         ¯7.4357
        ¯0.4372         ¯5.3564
         1.6601         12.6889
         0.5844         11.8429
         0.7811         15.9144
         1.2113         14.0024
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.636
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N


      Z←YY REGRESS XX[;5 6 7 8 9]

                          ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   5       1.3651E1        2.7301E0          7.1731E1
  RESIDUAL   6      2.2836E¯1       3.8061E¯2
TOTAL       11       1.3879E1

R SQUARE:  0.9835
STD ERROR: 0.1951
   COEFFICIENTS    T STATISTICS
        ¯1.0533         ¯5.506
         1.6163          7.9588
         0.5708          7.4587
         0.8371          9.1611
         0.4923          2.9297
         0.5895          2.3518
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.193
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
N


      Z←YY REGRESS XX[;5 6 7 9 10]

                          ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   5       1.3753E1        2.7505E0          1.3061E2
  RESIDUAL   6      1.2636E¯1       2.1059E¯2
TOTAL       11       1.3879E1

R SQUARE:  0.9909
STD ERROR: 0.1451
   COEFFICIENTS    T STATISTICS
         1.2118          2.7458
         1.1968          8.8303
         0.4692          9.0449
         0.5933         11.704
        ¯1.503          ¯2.6857
        ¯1.6201         ¯4.5118
```

APPENDIX G

CANDIDATE REGRESSION OUTPUT

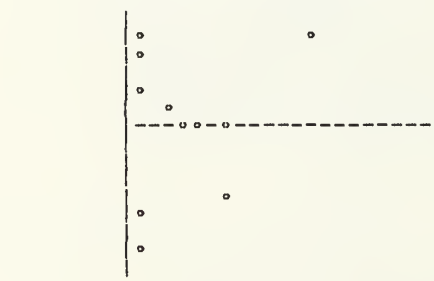
```
      CANDIDATE NUMBER 1
      Z←YY REGRESS XX[;5 6 7 8 9]
                              ANOVA
     SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION    5        1.3651E1        2.7301E0          7.1731E1
  RESIDUAL    6      2.2836E¯1        3.8061E¯2
TOTAL        11        1.3879E1

R SQUARE:  0.9835461
STD ERROR: 0.19509148
   COEFFICIENTS    T STATISTICS
        ¯1.0533          ¯5.506
         1.6163           7.9588
         0.5708           7.4587
         0.8371           9.1611
         0.4923           2.9297
         0.5895           2.3518
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.1934614
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0 4.5
RANGE OF Y: ¯0.3 0.4
```



```
        Z
  4.4150969     ¯0.075096904
  0.87175672     0.097243276
  0.45195269     0.094047306
  1.641921       0.048078954
  1.4371212     ¯0.057121164
  1.2390332     ¯0.0090331506
  2.4760623      0.31393775
  0.61157319     0.11142681
  0.78429782    ¯0.097297819
  1.7803141     ¯0.24031406
  0.61157319    ¯0.13357319
  0.78429782    ¯0.052297819
```

CANDIDATE NUMBER 2

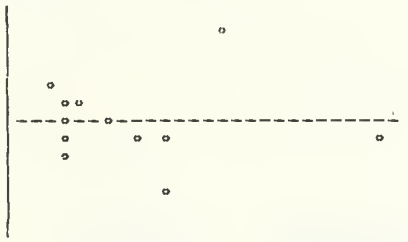
```
      Z←YY REGRESS XX[;3 5 6 7 9]

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   5       1.3783E1        2.7566E0          1.7229E2
  RESIDUAL   6       9.5998E¯2       1.6000E¯2
TOTAL       11        1.3879E1

R SQUARE:  0.99308324
STD ERROR: 0.12648973
   COEFFICIENTS    T STATISTICS
        ¯0.7333         ¯7.4357
        ¯0.4372         ¯5.3564
         1.6601         12.6889
         0.5844         11.8429
         0.7811         15.9144
         1.2113         14.0024
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.6364882
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.2 0.15
```



```
      Z

  4.3830354      ¯0.043035359
  0.94466212      0.024337877
  0.71806602     ¯0.17206602
  1.6859215       0.0040785452
  1.380768       ¯0.00076803007
  1.2297293       0.00027066743
  2.6649527       0.12504726
  0.59115126      0.13184874
  0.64263767      0.044362334
  1.6302871      ¯0.090287093
  0.59115126     ¯0.11315126
  0.64263767      0.089362334
```

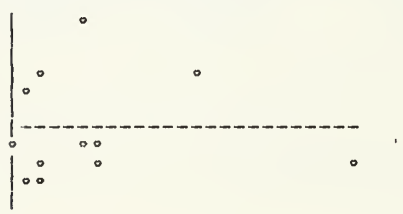
CANDIDATE NUMBER 3

```
      Z←YY REGRESS ⍉(4 12⍴C5,C6,(C7+C9),C8)

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3629E1        3.4072E0          9.5243E1
  RESIDUAL   7       2.5041E¯1       3.5773E¯2
TOTAL       11        1.3879E1

R SQUARE:  0.98195744
STD ERROR: 0.18913837
   COEFFICIENTS    T STATISTICS
         ¯0.9847         ¯6.0188
          1.566           8.4117
         0.5479           8.0278
          0.777          17.4655
         0.3841           4.4286
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.2876194
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0 4.5
RANGE OF Y: ¯0.4 0.4
```



```
      Z

  4.3835149     ¯0.043514865
  0.86982171     0.099178287
  0.43269714     0.11330286
  1.7621023     ¯0.072102341
  1.4232357     ¯0.043235695
  1.2203633      0.0096367063
  2.4600169      0.32998311
  0.62833171     0.094668289
  0.7411641     ¯0.054164095
  1.8142565     ¯0.27425646
  0.62833171    ¯0.15033171
  0.7411641     ¯0.0091640955
```

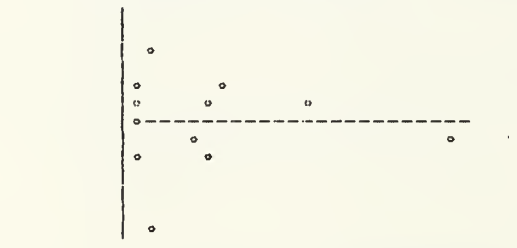
```
      CANDIDATE NUMBER 4


      Z←YY REGRESS ⍉(4 12⍴C5,C6,(C7+(C7*C9)),C8)

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3679E1        3.4197E0          1.1967E2
  RESIDUAL   7       2.0004E-1        2.8577E-2
TOTAL       11        1.3879E1

R SQUARE:  0.98558672
STD ERROR: 0.16904875
   COEFFICIENTS    T STATISTICS
         -1.1241         -7.5129
          1.1015          6.6648
          0.4608          7.6115
          0.6178         19.5861
          0.7814         10.1228
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 2.1829163
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.2 0.3
```



```
      Z
  4.4334668   ¯0.093466781
  0.82017993   0.14882007
  0.57622725  ¯0.030227249
  1.4067766    0.28322344
  1.458074    ¯0.078074034
  1.2815873   ¯0.051587275
  2.6486559    0.1413441
  0.62817665   0.094823354
  0.8214824   ¯0.1344824
  1.5807142   ¯0.040714168
  0.62817665  ¯0.15017665
  0.3214824   ¯0.089482404
```

```
      CANDIDATE NUMBER 5


      Z←YY REGRESS ⍉(4 12⍴(C5+(C5*C3)),C6,(C7+(C7*C9)),C9)

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3642E1        3.4104E0         1.0058E2
  RESIDUAL   7       2.3735E¯1       3.3908E¯2
TOTAL       11        1.3879E1

R SQUARE:  0.98289843
STD ERROR: 0.18414018
   COEFFICIENTS    T STATISTICS
         0.8836          5.4641
         0.5556          5.9432
         0.4192          6.2788
         0.4226         10.9485
         1.0735          8.5952
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 2.0063101
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.3 0.2

|          ∘
|∘ ∘
|  ∘
|  ∘
|---∘∘∘----------------∘-
|
|
|
|∘      ∘
| ∘
|

      Z

  4.3607772    ¯0.020777162
  0.80850381    0.16049619
  0.77395914   ¯0.22795914
  1.9137932    ¯0.22379325
  1.3630184     0.016981585
  1.224748      0.0052520013
  2.6099061     0.18009386
  0.68142394    0.041576065
  0.58324895    0.10375105
  1.5209483    ¯0.019051687
  0.68142394   ¯0.20342394
  0.58324895    0.14875105
```

```
      CANDIDATE NUMBER 6


      Z←YY REGRESS ⍉(4 12⍴(C5+(C5*C3)),C6,(C7+C9+(C7*C9)),C8)

                                ANOVA

     SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION    4        1.3692E1        3.4229E0          1.2791E2
  RESIDUAL    7       1.8732E-1       2.6760E-2
TOTAL        11        1.3879E1

R SQUARE:  0.98650316
STD ERROR: 0.16358617
    COEFFICIENTS    T STATISTICS
          1.0253          6.8648
          0.5352          6.5199
          0.4483          7.5045
          0.5259         20.3958
          0.3516          5.168
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 3.1742026
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.3 0.3
```



```
      Z

  4.378394      ¯0.038393962
  0.7605148      0.2084852
  0.83319851    ¯0.28719851
  1.591642       0.098357956
  1.4783478     ¯0.098347801
  1.2639854     ¯0.033985423
  2.7288768      0.061123222
  0.60114754     0.12185246
  0.69669162    ¯0.0096916213
  1.4743624      0.065637644
  0.60114754    ¯0.12314754
  0.69669162     0.035308379
```

```
      CANDIDATE NUMBER 7


      Z←YY REGRESS ⍉(4 12⍴C5,C6,(C7+C9+(C7*C9)),C8)

                                ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3752E1        3.4380E0          1.8932E2
  RESIDUAL   7       1.2712E-1       1.8160E-2
TOTAL       11        1.3879E1

R SQUARE:  0.99084083
STD ERROR: 0.13475928
   COEFFICIENTS    T STATISTICS
         0.9736         8.3779
         1.0703         8.1213
         0.4277         8.8759
         0.5238        24.6514
         0.4894         7.9835
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 1.3737869
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.2 0.2

|          ∘
| ∘
|
|∘∘
|∘--∘--------------------
|∘    ∘∘                ∘
|
|∘     ∘
|

      Z

  4.3893926    ¯0.049392636
  0.81540803    0.15359197
  0.51027769   ¯0.035722306
  1.7246519    ¯0.034651875
  1.4180981    ¯0.03809809
  1.2245956     0.0054043933
  2.5932259     0.19677407
  0.65259967   ¯0.070400333
  0.71824076   ¯0.031240756
  1.6876693    ¯0.14766929
  0.65259967   ¯0.17459967
  0.71824076    0.013759244
```

```
      CANDIDATE NUMBER 8


      Z←YY REGRESS ⍉(4 12⍴(C5+(C5*C6)),C6,(C7+C9+(C7*C9)),C8)

                                ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3594E1        3.3985E0          8.3423E1
  RESIDUAL   7        2.8516E-1       4.0738E-2
TOTAL       11        1.3879E1

R SQUARE:  0.9794536
STD ERROR: 0.20183591
   COEFFICIENTS    T STATISTICS
         1.5839          5.5404
         0.8049          5.0519
         0.6604          6.7293
         0.5225         16.4094
          0.521          5.4158
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 2.1715732
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.3 0.4

|
|            ∘
|∘
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∘
|      ∘
|
|------------------------
|∘   ∘∘                    ∘
∘ ∘                          '
| ∘
|      ∘
|
|

      Z

  4.439889    ¯0.099888956
  0.73496157   0.23403843
  0.62001967  ¯0.07401967
  1.5781963    0.11180365
  1.5879929   ¯0.20799295
  1.2819846   ¯0.051984635
  2.4825682    0.30743179
  0.57257343   0.15042657
  0.82744597  ¯0.14044597
  1.5793489   ¯0.039348862
  0.57257343  ¯0.094573429
  0.82744597  ¯0.095445969
```

```
      CANDIDATE NUMBER 9


      Z←YY REGRESS ⍵(3 12⍴(C5+C6+(C5*C3)),(C7+C9+(C7*C9)),C8)

                                ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   3        1.3662E1        4.5539E0         1.6755E2
  RESIDUAL   8       2.1743E-1        2.7179E-2
TOTAL       11        1.3879E1

R SQUARE:  0.9843338
STD ERROR: 0.16486045
   COEFFICIENTS    T STATISTICS
         0.9554          7.0732
         0.4712          8.3989
         0.5274         20.3193
         0.3449          5.0521
DO YOU WANT A PRINTOUT OF THE VARIANCE-COVARIANCE MATRIX?
N
DURBIN-WATSON: 2.777424
DO YOU WANT TO FORECAST A VALUE FOR Y?
N
DO YOU WANT TO SCAT RESIDUALS VS. PREDICTED Y?
Y
RANGE OF X: 0.5 4.5
RANGE OF Y: ¯0.3 0.3

|
|∘
∘
|
|
|      ∘∘      ∘
|∘-----------------------∘-
∘∘     ∘
|
|     ∘
|
|
| ∘

       Z

  4.3382219     0.0017780908
  0.70118071   ¯0.26781929
  0.82246976   ¯0.27646976
  1.6523549    ¯0.037645088
  1.4547703    ¯0.074770323
  1.3649886    ¯0.13498863
  2.7246459     0.065354121
  0.54088598   ¯0.18211402
  0.72780677   ¯0.040806773
  1.5089824     0.031017642
  0.54088598   ¯0.062885984
  0.72780677    0.004193227
```

APPENDIX H

MODEL APPLICATION

```
      Z←YY REGRESS ⍵(4 12⍴C5,C6,(C7+C9+(C7*C9)),C8)

                              ANOVA

    SOURCE  DF      SUM SQUARES      MEAN SQUARE          F-RATIO
REGRESSION   4        1.3752E1        3.4380E0          1.8932E2
  RESIDUAL   7        1.2712E-1       1.8160E-2
TOTAL       11        1.3879E1

R SQUARE:  0.99084083
STD ERROR: 0.13475928
   COEFFICIENTS    T STATISTICS
        -0.9736         -8.3779
         1.0703          8.1213
         0.4277          8.8759
         0.5238         24.6514
         0.4894          7.9835


DO YOU WANT TO FORECAST A VALUE FOR Y?
Y

      KRESTA I

ENTER X VECTOR (4 VALUES)
⍞:
      .3087 0 3.592 .773
FORECAST OF Y VALUE: 1.6167418
VARIANCE OF FORECAST ERROR: 0.021569538
DO YOU WANT TO FORECAST A VALUE FOR Y?
Y

      KRIVAK II

ENTER X VECTOR (4 VALUES)
⍞:
      1.03 0 1.6507 0
FORECAST OF Y VALUE: 0.99346003
VARIANCE OF FORECAST ERROR: 0.023300636
DO YOU WANT TO FORECAST A VALUE FOR Y?
Y

      MIRKA II, MINEGUMO, ISUZU

ENTER X VECTOR (4 VALUES)
⍞:
      1.03 0 1 0
FORECAST OF Y VALUE: 0.65259967
VARIANCE OF FORECAST ERROR: 0.024144897
DO YOU WANT TO FORECAST A VALUE FOR Y?
Y

      SHIRANE

ENTER X VECTOR (4 VALUES)
⍞:
      3.146 3.142 2.591 0
```

```
FORECAST OF Y VALUE: 5.0946477
VARIANCE OF FORECAST ERROR: 0.17329463
DO YOU WANT TO FORECAST A VALUE FOR Y?
Y

      ISHIKARI

ENTER X VECTOR (4 VALUES)
□:
      .3087 0 1 1.478
FORECAST OF Y VALUE: 0.60400775
VARIANCE OF FORECAST ERROR: 0.025220762
```

LIST OF REFERENCES

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